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Review and Assessment of Available Indicators for Evaluating Sustainable Land Management

Centre for Land and Biological
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Canada

Review and Assessment of Available Indicators for Evaluating Sustainable Land Management

P. Neave, V. Kirkwood and J. Dumanski

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Abstract


The need to determine whether current land management practices and agricultural systems are environmentally and economically sustainable has led to the development of a framework for assessment of sustainable land management (SLM). Indicators of SLM can be grouped into four categories: physical, agronomic, economic and social. In this report, some indicators for SLM are reviewed, and selected indicators are assessed using 1991 Census of Agriculture data.

Indicators were selected on the basis of criteria from the literature, and availability of data. Indicators that appear useful in assessing sustainable land management include: historical trend of cropping intensity, nutrient budgets, physical land flexibility, yield variability, windbreak density, crop influence on soil quality, conservation tillage, historical trend of area in summerfallow, gross margin with and without government subsidies, and debt load.

Résumé

Une besion de déterminer si les pratiques courantes de gestion des terres et les systèmes agricoles d'aujourd'hui sont environnementalement et économiquement durables a été constaté. Ce besoin a mené au développement d'une structure pour l'étude de la gestion durable des terres. Les indicateurs de la gestion durable des terres peuvent être regroupés en quatre catégories: physiques, agronomiques, économiques et sociaux. Dans ce rapport, certains indicateurs de la gestion durable des terres sont révisés et des indicateurs sélectionnés sont étudiés en relation avec les données recensement de l'agriculture de 1991.

Les indicateurs ont été sélectionnés sur la base de critères tirés de la littérature et de la disponibilité des données. Les indicateurs qui se sont avérés utiles dans l'étude de la gestion durable des terres renferment l'évolution de la tendance à la culture intensive, le bilan des éléments nutritifs dans le sol, la flexibilité des sols, la variation des rendments, la densité de brise-vents, l'influence des cultures sur la qualité du sol, l'utilisation de pratiques de conservation, l'évolution de l'utilisation de la jachère, les marges brutes d'opération avec ou sans les subventions gouvernementales et l'endettement.



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Introduction

This report investigates some potential indicators for assessing the sustainability of agricultural land management in Canada. The focus will be on the sustainability of agricultural resources. Data from the 1991 Census of Agriculture were used, where possible, to determine indicators, because the data are current, and equally representative of all parts of the country.

Rapidly expanding populations and a fixed resource base have focused attention on sustainable development and on sustainable agriculture. Defining sustainable agriculture is not an easy task, partially because of the wide scope of the subject. Simply put, sustainable means using resources to meet the needs of today without compromising options for the future (WCED, 1987). Sustainable agriculture can be defined as agricultural systems that maintain environmental quality, satisfy human needs, and are profitable and productive over long periods of time (Treitz, 1991; Keeney, 1989). It is not necessarily synonymous with low input sustainable agriculture (LISA), or with alternative, ecological, organic agriculture, or any other specific class of production techniques. Nor are sustainable agriculture systems necessarily static; rather, they evolve over time in response to changing biophysical, economic and social conditions. In order for agriculture to be viable in the long term, it is important that the natural resource base be conserved, so that it can withstand the intensified use that will come with increasing population pressures (Dumanski et al., 1991).

MacRae et al. (1990) state that sustainability can be reached in North America through three stages: efficiency, substitution, and redesign. In the first stage, inputs and environmental impacts are reduced by, for example, banding fertilizers and monitoring pests prior to pesticide application. In the substitution phase, harmful inputs are replaced by more environmentally benign sources, such as replacing non-specific pesticides with biological controls. In the redesign stage, the system is made more ecologically and economically diverse, self-reliant in resources, and self regulating. It is suggested that true sustainability must build on the positive elements of each stage. Crews et al. (1991) identified five conditions, based on energetic and ecological principles, which must be met for agriculture to be sustainable. These were: energy yield must be greater than the energy used in the production process; soil fertility (productivity) must be maintained; water resources must not be depleted; human health must not be jeopardized; and species diversity must be maintained.

Ideally, sustainable agriculture would not only maintain the quality of the environment, but could enhance quality (FPACES, 1990) by rebuilding partially degraded ecosystems.

The need to assess whether current land management practices and agricultural systems are sustainable has led the International Board for Soil Research And Management (IBSRAM) to develop a framework for evaluation of sustainable land management. Sustainable Land Management (SLM) is a package of technologies which individually or in aggregate contribute to achieving sustainable agriculture. It differs from sustainable agriculture by going beyond addressing the need for sustainable agricultural development to describe how this sustainability is to be achieved (Dumanski et al., 1991). Part of the framework for evaluation of SLM is to develop a number of indicators and thresholds of sustainability. Indicators will be used to determine whether a system is sustainable, to detect deviations from intended trends (IBSRAM, 1991), and to identify regions where adjustments are required. Thresholds are measures of the point beyond which the system can be judged unsustainable.

The Federal-Provincial Agriculture Committee on Environmental Sustainability (1990) envisioned long term goals that aim toward sustainable agriculture. These goals were to develop:

1. A secure and well-managed resource base of agricultural land and soil to support the long-term productivity and competitiveness of the Canadian agri-food industry;
2. An agri-food sector that contributes to improved surface and groundwater quality through the use of environmentally sustainable production and processing practices;
3. An agri-food sector that has adapted itself to, and manages on a sustainable basis, the surface and groundwater resources available to it;

4. Canada's agri-food sector and wildlife resources to be managed for sustainability and long-term benefits;
5. An agri-food sector that is able to respond to air and climate change, and which does not itself contribute to air and climate problems;
6. An agri-food sector that is more energy efficient, less polluting and less dependent on non-renewable energy sources;
7. A major reduction in the impact of pollution on air, soil and water resources used by the agri-food sector. An agri-food sector that has minimized its contribution to air, soil and water degradation and pollution; and
8. Canada to have an accessible and sufficiently diversified genetic resource base that can be effectively utilized to assure the sustainability of agriculture for future generations.

Agriculture and Agri-Food Canada has identified several uses for indicators, including the need to provide a framework to incorporate environmental factors into the decision making process, and a need for information on the sustainability of agriculture. Agriculture and Agri-Food Canada is also committed, in the Green Plan and in the Federal-Provincial Agriculture Committee on Environmental Sustainability, to create a set of environmental indicators for agriculture. The Science Council of Canada (1992) has also recommended the development of indicators of soil and water quality, and physical and biological indicators of sustainable agriculture. The Canadian Environment Advisory Council (Potvin, 1991), has similarly suggested that constraints (thresholds), and directions of change would be useful information in the decision making process.

Framework for Assessment of Sustainable Land Management

The Framework for Assessment of Sustainable Land Management (FESLM) lists five objectives or 'pillars' on which sustainable land management is founded. These are:

- 1) **Productivity:** maintain or enhance production/services. The return from SLM may extend beyond material yields from agricultural and non-agricultural uses to include benefits from protective and aesthetic aims of land use.
- 2) **Security:** reduce the level of production risk. Management methods that promote balance between a land use and prevailing environmental conditions, reduce the risks of production; conversely, methods that destabilize local relationships increase that risk.
- 3) **Protection:** protect the potential of natural resources and prevent degradation of soil and water quality. The quantity and quality of soil and water resources must be safeguarded, in equity for future generations. Locally, there may be additional conservation priorities such as the need to maintain genetic diversity or preserve individual plant or animal species.
- 4) **Viability:** be economically viable. If the land uses being considered are locally not viable, the use will not survive.
- 5) **Acceptability:** be socially acceptable. Land use methods can be expected to fail, in time, if their social impact is unacceptable. The populations most directly affected by social and economic impact are not necessarily the same. (Smyth and Dumanski, 1993).

For a system to be sustainable, all five of these objectives must be attained.

The productivity pillar includes the concept of the maintenance or enhancement of agricultural yields, and also includes other protective and aesthetic benefits accrued through improved land use. Security implies promoting a flexible interface between a land use and the prevailing environmental and economic conditions. This would reduce the risk created by adverse events such as declining commodity prices or climate change. Conservation involves conserving the quality and quantity of natural resources (air, soil, water, genetic

diversity, etc.) in order to preserve the diversity of future options. Viability refers to the economic performance of the land use system; the system must perform favourably when all costs, returns and labour requirements are taken into consideration. Acceptability encompasses the social impact of the land use system on the farming community and on the expectations of society.

Indicators for SLM can be divided into four categories: physical, agronomic, economic and social (Dumanski, 1994). A collection of indicators is needed to describe the different dimensions of SLM, because of the complexities of issues which affect and control SLM. To be truly effective, indicators must be tailored to reflect the land uses, management practices and the environment — soil, climate and market — where they will be applied.

Variables, Indicators and Thresholds

Many quantitative and qualitative variables (eg. soil salinity, bulk density, net margin) can be used to describe the physical and economic environment within which a land management system operates. When compared through time, these variables, either individually or in groups, can be indicators of the performance of a system (eg. increasing soil salinity, decreasing bulk density, decreasing net margin). A threshold is the value of an indicator beyond which the system can no longer be considered to be sustainable. Threshold values may vary between systems; for example, what is considered to be an unacceptably high level of soil salinity in one system, might be acceptable within another.

Criteria for choosing indicators

Criteria have been proposed for choosing "ideal" indicators of sustainability. Participants at a national planning workshop (Environment Canada, 1988) suggested that a systems perspective was required, and that composite indicators of system health may be more desirable than individual measurements. Indicators which use averages of many areas were not recommended, because patterns were obscured when regions are grouped together (OECD, 1993). The US-EPA Environmental Monitoring and Assessment Program suggested that ideal indicators: are potentially the most sensitive to change in ecosystem condition, have broad application, and have the potential to provide the lowest measurement variability (Walker and Jones, 1992). Rapport (1990) suggested the following criteria: relevance, reliability with respect to current technical capabilities, and robustness, or the ability to be responsive to a wide variety of pressures, rather than to specific circumstances. At the International Workshop on Sustainable Land Management for the 21st Century (Dumanski, 1994), participants were asked to identify indicators that are measurable and reportable, and which reflect good or bad land use practices.

Review of Available Indicators

Four categories of indicators are considered in this report: physical, agronomic, economic and social. The indicators are presented in tabular form for ease of comparison. Judgements are made on whether the indicators have low, medium or high potential to provide useful information, and whether they are best suited for use on a national or a regional basis.

No individual indicator will suggest sustainability or non-sustainability on its own. Combinations of indicators covering various aspects of agriculture as well as off-site impacts will need to be considered in order to assess the sustainability of systems.

1. Physical

Table 1. Physical indicators of sustainability.

Indicator	Units	Definition and Discussion	Rating
Physical Land Flexibility	Ratio	Measures the potential of a region to support diversified production, which enhances its capability to withstand climatic and economic stress (Dumanski et al., 1988).	high, regional
Bare Ground to Vegetation Cover	Ratio	Shows the potential for soil erosion and land degradation (Hamblin, 1992).	high, national, regional
Nutrients	ppm or g/L	N, P and K concentrations can be monitored in surface and groundwater to estimate nutrient loss from agricultural soil.	high, regional
Erosion Rate	t/ha	Measures the degree of land degradation. Can be predicted using EPIC or other erosion models (FPWGPR, 1991; Sharpley and Williams, 1990).	high, regional
Soil Salinization	ha	Indicative of unsustainable land management and poor water management.	high, regional
Plant Available Water Capacity	%	Has an important influence on crop yield, since it is affected by texture, organic matter and structure.	high, regional
Soil Organic Matter	Various	Affects aggregation, water infiltration, nutrient retention and biological activity. There are several ways to measure organic matter (Gregorich et al., 1993).	high, regional
Bulk Density	g/cm ³	Reflects porosity and soil structure.	high, regional
Cation Exchange Capacity	meq/100g soil	Affects the capacity of the soil to retain and release nutrients.	high, regional
pH		Affects nutrient availability and crop growth.	high, regional
Electrical Conductivity	micro-ohms/cm	Indicative of existing and potential soil salinity problems.	high, regional
Suspended Solids and Turbidity	kg/L	Monitored in lakes and streams to determine soil loss and sedimentation rates.	high, regional
Pesticides	%	Pesticide residues can be monitored in surface and groundwater, in the soil itself, and in animal tissue, to determine levels of contamination in the environment.	high, regional
Biological Oxygen Demand and Bacterial Activity		Affected by water pollution. Bacteria and other organisms respond to pollution by increasing their respiratory rate and activity (Bott, 1973).	high, regional
Drainage Problems		The development of drainage problems, eg. ponding, indicates poor soil management (Smyth, 1993).	medium, regional

Water Limit	m ³	To grow sufficient food to support one person requires 1000 - 2000 m ³ /yr of fresh water. Limit reached when population requirements exceed total amount of fresh water available (Bryson, 1989).	medium, national, regional
Sunlight Limit	Persons/ha	Threshold of 5.56 persons/ha can be supported by using all sunlight falling on arable land (Bryson, 1989). Ratios higher than this cannot be sustained without food imports.	medium, regional, national
Maximum Rooting Depth	cm	Can be used to identify compaction or root impedance problems, and restrictions to water movement.	medium, regional
Qualitative and Visual Indicators	Various	Soil crusting, rills, gulleys, ripple marks, sand dunes, exposed roots, salt crust, acid- or salt-tolerant weeds, lack of fertilizer response, standing water (Arshad and Coen, 1992)	medium, regional
Compaction	Ratio	Ratio of land with compacted soil to total cropped area.	medium, regional
Particle Size Distribution	%	A change may indicate an erosion problem.	low, regional
Depth of Water Table	m	Depth to the water table or to the saturated zone may correspond to potential salinity problems in the prairie region.	low, regional

2. Agronomic

Table 2. Agronomic indicators of sustainability.

Indicator	Units	Definition and Discussion	Rating
Cropping Intensity	Ratio	Ratio of area of land in crops to total area of agricultural land. (Alexandratos, 1988)	high, regional
Summerfallow Chemical Weed Control	Ratio	Ratio of summerfallowed land under chemical-only or a combination of chemical and tillage weed control vs summerfallowed land under tillage-only weed control.	high, regional
Summerfallow and Soil Moisture	ha or Ratio	Area in summerfallow where the soil moisture levels at seeding are above established thresholds (FPWGRP, 1991) or proportion of farmers who use soil moisture as a factor in deciding to summerfallow (Goddard, 1992).	high, regional
Summerfallow Tillage Weed Control	#	Number of times summerfallow fields are cultivated per year. Increased cultivation promotes the potential for soil degradation.	high, regional
Windbreaks	km/km ²	Length of windbreaks per km ² arable land which is susceptible to wind erosion. This estimates efforts to control soil erosion. Windbreaks also provide wildlife corridors between non-agricultural areas.	high, regional
Salinity Control	Ratio	Number of farms using salinity control vs number of farms requiring salinity control. Shows adoption of salinity control technology.	high, regional
Crop Rotation		The use of crop rotations with forages to control erosion and build resources illustrates good land stewardship (Environment Canada, 1992).	high, regional
Crop Rotation	Ratio	Proportion of cropped land in crop rotation. Indicative of diversity of production.	high, regional
Nutrient Balance	Ratio	Nutrients extracted by crops relative to fertilizer and manure applied (Flaten and Hedlin, 1988).	high, regional
Crop Influence	Ratio	Ratio of 'soil building' crops (eg. alfalfa) to 'soil degrading' crops (eg. tobacco). The proportion in high, medium and low soil degradation risk crops or deep rooting crops indicates potential, regional soil degradation.	high, regional
Plant Health	Various	Nutrient deficiencies and recurrent plant diseases are indicators of management problems, as are the severity of pest and disease damage (Smyth, 1993).	high, regional
Yield Variability		The variability of crop yield assesses the risk of production for a region, and hence also the sustainability (Dumanski et al., 1991).	high, regional
Nutrient Management	Ratio	Ratio of area using commercial fertilizer to area using manure; or ratio of number of farmers using manure as fertilizer to number of farmers with livestock.	medium, regional
Reclamation Measures	ha	The use of gypsum, ripping and deep ploughing are indicative of problems with previous soil management practices, and represent efforts to rehabilitate degraded land (Smyth, 1993).	medium, regional
Production Practices Matched to Land Capability	Ratio	Proportion of land where production practices are well suited to the limitations of the land (eg. permanent cover or forages on sloping land).	medium, regional

Degraded Land Rehabilitation	ha	Land rehabilitated through the use of forage crops or reforestation is indicative of stewardship (Environment Canada, 1992).	medium, regional
Fertilizer Use	%, or kg/ha	Percent of cropland receiving fertilizer, or fertilizer use per ha of crops. Unsustainability is suggested if the fertilizer use ratio increases over time. Must distinguish between application aimed at building the soil vs soil mining practices.	medium, regional
Improved Area	ha/yr	An increase in the area of improved land is an indicator of increased production intensity (Environment Canada, 1992). Caution: improvements on marginal land may have a negative impact on sustainability.	medium, regional
Pest Management	Ratio	Ratio of land where only pesticides are used vs land where an integrated pest management system is used (Environment Canada, 1992).	medium, regional
High Residue Crops	Ratio	Ratio of area in high residue crops vs area in low residue crops.	medium, regional
Soil Moisture Conservation	#	Number of farmers using practices to trap and conserve soil moisture in the prairies.	medium, regional
Water Harvesting	m ³	Reuse of drainage water for irrigation, as long as water quality is maintained (Smyth, 1993). Improved soil water management in dryland conditions.	medium, regional
Soil Organic Matter Enhancement	Ratio	Proportion of land where soil organic matter is enhanced or maintained through green manuring, residue management and efficient use of manure (Environment Canada, 1992).	medium, regional
Liming Intensity	Ratio	Ratio of land limed vs land requiring lime (Environment Canada, 1992).	medium, regional
Field Size	ha	A large field size in an erosion-prone area may promote the potential for erosion (Environment Canada, 1992).	poor, regional
Cereal Harvest Area	ha	Compare cereal harvest area to total agricultural land. (Kloet, pers. com.)	poor, national
Cereal Production per Farmer	t/farmer	Production intensity per farmer (Kloet, pers. com.)	poor, national

3. Economic

Table 3. Economic indicators of sustainability.

Indicator	Units	Definition and Discussion	Rating
Gross Margin	\$/ha	Total gross farm receipts minus total farm operating expenses. If negative, this indicates that the operation is losing money. This can be calculated with or without government subsidies.	high, regional, national
Gross Profit	\$/ha	Ratio of gross margin to operating expenses. Farms with high gross profit are achieving efficiencies in terms of input dollars.	high, regional
Net Margin	\$/ha	Calculated as the difference between total farm receipts and total farm expenses (expenses include interest paid on loans, money set aside for operator labour, and depreciation on capital).	high, regional
Profitability	Ratio	Change in sales vs change in expenses over the same time period.	high, regional
Debt Load	\$	Interest paid on debt vs total capital value or gross margin.	high, regional
Income or Yield Lost to Erosion	\$/ha \$/t soil	Indicators of loss in production potential due to loss of natural resources	high, regional, national
Government Support	%	Proportion of income that is derived from government support payments.	high, regional
Resource Accounting	\$/ha	Depreciation of natural resources is the capitalized present value of the reduction in future income of this asset as a result of decay or obsolescence (Repetto, 1992). If the quantity and quality of natural resources are not maintained, future consumption opportunities will decline (Alberta Discussion Paper, 1992).	high, regional
Economic Resilience	Time	The ability of a system to recover from a disturbance (eg. the time required for gross margin to return to "normal" after a drought).	high, regional
Farm Type		Classifying farms on the basis of the percent of income received from each crop (Statistics Canada, 1992) can be an aid in assessing the economic viability of various farming systems	medium, regional
Forest Products	Ratio	Ratio of number of farms selling forest products to total number of farms; or ratio of receipts from sales of forest products to gross farm receipts. Indicates value of forest products to the farm economy, and also economic diversity	medium, regional
Crop Yield	t/ha	A threshold of 1.6 t/ha distinguishes between commercial and subsistence agriculture (FAO, 1984). Values < 1.6 t/ha are considered a risk factor for the country.	medium, regional
Operating Efficiency	Ratio	Ratio of total sales to expenses. Measures the efficiency with which input dollars are used to generate sales.	medium, regional
Capital Use Efficiency	Ratio	Ratio of sales to investment.	medium, regional

Return to Labour	Ratio	Gross margin vs number of hours of labour put into the farm operation.	medium, regional
Return to Management	Ratio	Net margin vs number of hours put into a farm operation.	medium, regional
Return from Capital	Ratio	Gross margin vs capital	medium, regional
Expenditures	\$/ha \$/animal	The expenditure on seeds, fertilizer, pesticides, machinery upkeep, feed, veterinary services and electricity per unit area or per animal.	medium, regional
Input Costs/unit area or /unit yield	\$/ha or \$/t	Ratio of input costs (fertilizer, lime, seed, pesticides and farm machinery) to area of improved cropland (Environment Canada, 1992; Smyth, 1993). Alternatively, the input costs per unit yield.	medium, regional

4. Social

Table 4. Social indicators of sustainability.

Indicator	Units	Definition and Discussion	Rating
Marginal Land Use	ha	Increased use of marginal land (eg. new seeding on class 5, 6 or 7 lands) (Environment Canada, 1992), or retirement from active cropping (EMA, 1992)) is indicative of the quality of stewardship.	high, regional
Conservation Tillage	Ratio	Area of land under conservation tillage vs area of land under conventional tillage. Shows level of resource conservation and adoption of low input management practices (FPWGPR, 1991).	high, regional, national
Conservation Practices	Ratio	Ratio of number of farms using conservation practices (eg. forage rotations, winter cover crops, grassed waterways, strip cropping, etc.) to control soil degradation vs number of farms that require these practices.	high, regional
Summerfallow	ha	A decrease in the area of land in summerfallow suggests an increase in sustainability (Environment Canada, 1992; Coote, 1983).	high, regional
Government Support	%	Proportion of income that is derived from government support payments.	high, regional
Loss to Urbanization	ha	Productive land lost to urbanization is a poor sustainable land management practice (Environment Canada, 1992).	high, regional
Environmental Accounting	\$/ha	Considers the value of the resource itself, plus other peripheral or intrinsic values (eg. the value of a standing forest in conserving soil, cleaning air and water, providing habitat for wildlife, and supporting recreational activities (Constanza et al., 1991)). A similar example can be envisioned for wetlands in agricultural systems. Difficulty: assigning a dollar value to intrinsic values.	high, regional
Wetland Management	ha	The area of wetlands converted to crops or rehabilitated, or the width of uncultivated buffers around wetlands, are indicative of the quality of land stewardship (EMA, 1992). Good wetland stewardship increases regional water storage potential and encourages wildlife.	medium, regional

Assessment of Selected Indicators

In the above sections, a number of variables with the potential to be used as indicators were described. It bears repeating that these variables do not, in themselves, illustrate the sustainability or unsustainability of a particular system. It is only when the value of a variable or group of variables under study, consistently, over a period of years, exceeds the threshold value for unsustainability, or shows a definite trend toward that threshold, that the system in question can be deemed to be unsustainable.

In this section, the value of several of these potential indicators for assessing sustainable land management will be discussed. In order to study a variety of farming systems, these indicators were determined primarily for Alberta, Ontario and P.E.I. using census data, but other provinces were used in cases where data were limited.

In most cases, an individual indicator can only be used in a comparative sense, i.e. to suggest that one system is more sustainable than another. For example, farms with several years of positive net returns are more likely to be sustainable than farms in the same region with several years of negative net returns. Indicators from all five pillars of sustainable land management need to be considered together in order to make a complete assessment of the sustainability of a land management system.

1. Physical

Physical land flexibility. Physical land flexibility (PLF) (Dumanski et al., 1988) is a measure of the degree to which current yields in an area are approaching potential yields. It is also a measure of the degree of flexibility to buffer against outside stress. PLF reflects the ability of a region to diversify production, and its capability to withstand climatological and economic stress.

Figure 1 shows the results of a comparison of PLF values to a regional maximum for the prairie provinces. Southern Manitoba has the highest physical land flexibility, followed by areas in the Black Chernozemic soil zone in Saskatchewan and Alberta. These areas have the highest production capacity and are highly responsive to management (Dumanski et al., 1988). These factors are reflected in the high physical land flexibility index values. Next in order of decreasing PLF are areas in the Gray soil zone in western Manitoba, eastern and northern Saskatchewan, and northern and western Alberta. These areas are less dependable in terms of production than the Black soil zone. Lowest in physical land flexibility and dependability are the Dark Brown and Brown soil zones in southern Saskatchewan and Alberta. Land use diversity and cropping options are restricted in these zones, although these areas often have the most reliable weather for harvest and the highest quality grain

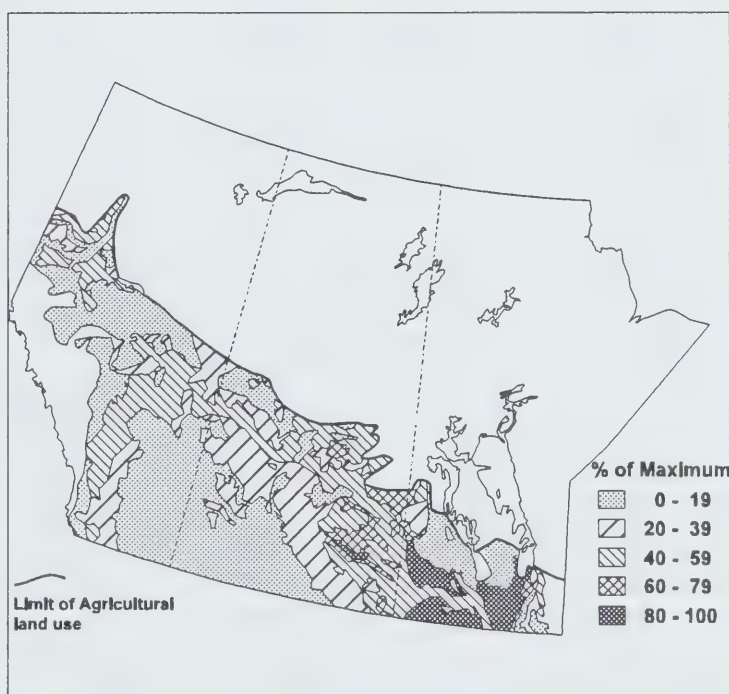


Figure 1. Physical Land Flexibility for eight crops in the prairie provinces compared to the regional maximum of 5.03 found in the Red River Plain. From Dumanski et al. (1988).

(Dumanski et al., 1988).

Physical land flexibility is a static factor; if regional soil and climate conditions do not change, PLF will not change. Its main use is as a tool to assess production risk, as it identifies areas where land use may be unable to cope with climatic or economic stress, and where there is little opportunity to diversify production.

2. Agronomic

Cropping intensity. Cropping intensity has increased in Alberta, Ontario and P.E.I. over the last 40 years (Figure 2). In Alberta this increase in intensity coincides with a small increase in total farm area (1986 census), but in Ontario and P.E.I. intensification has increased while total farm area has decreased. This suggests that intensification is occurring on better quality lands, most of which are already in cultivation. This observation is in agreement with earlier conclusions that most of the better quality lands in Canada are already in production (Dumanski and Smyth, 1994).

However, the level of intensity of cropping systems alone is not an indicator of sustainability. It could become a useful indicator if it could be compared to land quality, i.e. the change in the intensity of use of marginal lands. Unfortunately the data necessary from the census and the Canada Land Inventory have not yet been reconciled to enable this analysis.

Yield variability. Yield variability in Manitoba has been estimated by a statistical assessment of actual yields in Agroecological Resource Areas¹ (Dumanski, et al., 1992). Figure 3 shows the increase in the variation in the mean wheat yield and the standard deviation in ARA 12 in Manitoba. This increase suggests an increase in yield variability and thus an increased production risk. Increased production risk is an indicator of either increased environmental variability (especially climate) or a lack of management response to changing conditions. Increased production risk suggests unsustainability.

Summerfallow. Summerfallow use was highest in southern Alberta and Saskatchewan and consistently low in Manitoba (1991 census). Summerfallowing leaves soils highly vulnerable to degradation (Coote, 1983), and it may not be compatible with sustainable land management

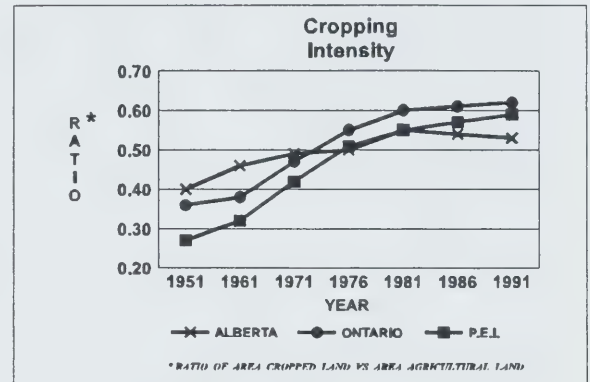


Figure 2. Historical trend of cropping intensity from 1951 - 1991 for Alberta, Ontario and P.E.I.

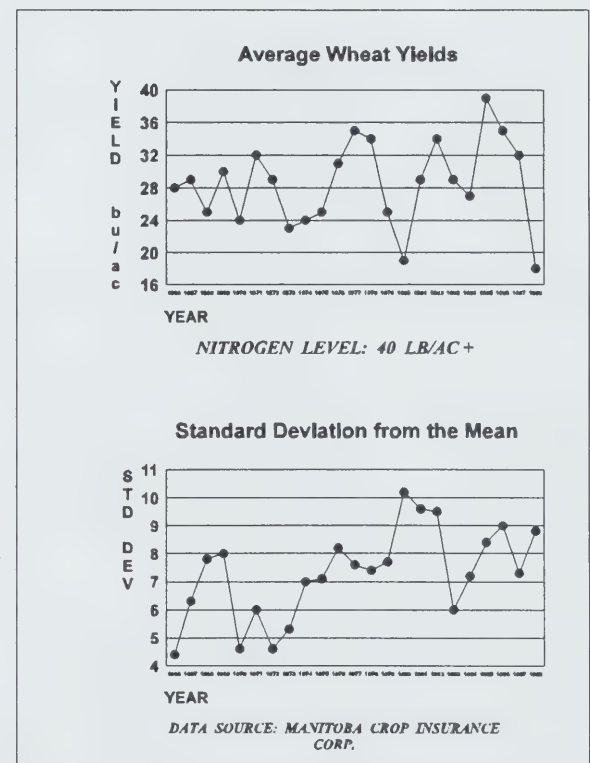


Figure 3. Variability and standard deviation of wheat yields in ARA number 12, Manitoba. From Dumanski et al. (1992).

¹ Agroecological Resource Areas (ARAs) are biophysically homogenous units at a scale of 1:2 million, based on ecoclimatic zonation, landform and soil characteristics.

unless erosion control practices and soil-conserving tillage practices are used. The ratio of area in summerfallow to area in cropland has decreased from 1951 to 1991 in all three prairie provinces, and this decline has been most noticeable over the past 15 years (Figure 4). However, summerfallow still occupies 16%, 30% and 6% of cropland in Alberta, Saskatchewan and Manitoba respectively.

The use of chemical-only weed control on summerfallowed land is minimal in the prairie provinces, averaging 4.0%, 3.5% and 2.8% for Alberta, Saskatchewan and Manitoba respectively. The proportion of area in combined chemical and tillage weed control varies throughout the prairie provinces to a high of more than 40% in some parts of southern Alberta and southwestern Saskatchewan. Chemical weed control, and combination tillage and chemical weed control, is preferable to tillage-only weed control of summerfallow, since excessive tillage breaks up aggregates, which leaves the soil vulnerable to erosion (Coote, 1983).

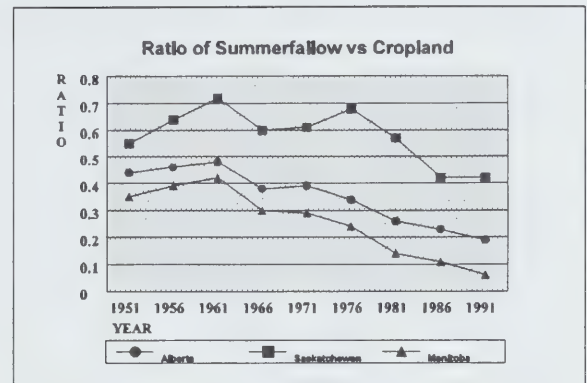


Figure 4. Ratio of area in summerfallow to area in cropland for Alberta, Saskatchewan and Manitoba from 1951 - 1991.

Nutrient management. Nutrient budgets can be used to assess whether the soil is being built up or mined for nutrients. In the prairie provinces, the work of Flaten and Hedlin (1988) was continued up to 1991, using the census data (Table 5). Coupland (1982) and the Fertilizer Institute (Asselstine and Girard, 1992) have also done work in this area. A simple algorithm was used to determine fertilizer addition using census and Fertilizer Institute data. Crop uptake of nutrients was determined by comparing uptake and area of crops in Coupland (1982) to census data. From 1976 to 1986 more P was being added to prairie soils than was removed by crops, indicating a net increase in P reserves over this period. However, more N was removed by crops than was added through fertilizer from 1976 to 1986. In 1991, less fertilizer was applied to the soil. Also, the area of cropland increased, partially due to a decrease in area of summerfallow. This combination of more cropland and less fertilizer resulted in increased crop uptake/fertilizer addition ratios, and may be related to the economic conditions during this period. More N and P was being removed from the soil by crops than was being added through fertilizers. The increase in the ratio from 1976 to 1991 is an unsustainable trend.

Year	Crop uptake (t,000's)		Fertilizer used (t,000's)		Crop:Fertilizer ratio	
	N	P	N	P	N	P
1971	623	110	128	59	4.86	1.86
1976	800	126	363	131	2.20	0.96
1981	898	153	652	175	1.38	0.87
1986	1133	192	896	202	1.26	0.95
1991	1485	314	668	202	2.22	1.83

Table 5. A continuation of the nutrient budget of Flaten and Hedlin (1988) for nitrogen and phosphorus in the prairie provinces. The 1991 figures were determined using census data, and information from both Coupland (1982) and the Fertilizer Institute (Asselstine and Girard, 1992).

Crop influence. Crop influence on soil degradation was determined by calculating the proportion of cropland in very high, high, medium and low soil degradation risk crops (Table 6). There is very little cropland in the very high and high degradation risk categories in Alberta (Figure 5), although some land is in sunflowers, potatoes and sugar beets. The majority of land in Alberta is under medium degradation risk crops (grains and oilseeds), the area of which has decreased slightly from a high of more than 90% of cropland in 1951 to less than 80% of

cropland in 1991. This decrease from grains and oilseeds has been accompanied by an increase in forages (low degradation risk), the proportion of which increased from 10% to 20% of cropland over the same period.

Very High	High	Medium	Low
Silage Corn (0.64)	Grain corn (0.46)	Spring wheat (0.23)	Alfalfa (0.02)
Tobacco (0.64)	Potatoes (0.45)	Durum wheat (0.23)	Tame hay (0.02) (including clover)
Vegetables (0.70)	Sunflowers	Oats (0.23)	Forage for seed (0.02)
	Soybeans (0.49)	Mixed grains (0.23)	
	Dry field peas	Barley (0.23)	
	Sugar beets	Winter wheat (0.21)	
	Field beans	Winter rye (0.21)	
		Buckwheat	
		Canola	
		Mustard seed	
		Flax	

Table 6. Common crops and their degree of soil degradation risk. C factors (Wischmeir and Smith, 1978) are in brackets.

In Ontario and P.E.I. the proportion of cropland in very high degradation risk crops increased from 1951 to 1976, and then stabilized at its current proportion of 5% and 2% of cropland respectively (Figure 5). The proportion of land in high degradation risk crops has steadily increased to the 1991 value of 42% of cropland in Ontario and 24% in P.E.I.. This increase is due to expansion of grain corn area in Ontario, and potato area in P.E.I.. In Ontario, the high degradation risk crops have replaced cereals and forages (medium and low degradation risk crops), while in P.E.I. the area in forages has decreased.

Sustainable land management requires that soil erosion and degradation risks be minimized. Among the provinces studied, the trend in Alberta appears to be toward crops which provide better soil erosion control, while in Ontario and P.E.I., the opposite is true. In order to evaluate whether this is a trend toward unsustainability in the latter two provinces, the crop influence variable must be studied in conjunction with data on the extent of other erosion control practices and with figures showing the actual amount of soil erosion taking place.

Windbreaks. Windbreak density was generally low throughout the country, but its use was concentrated in certain areas (Figure 6). In Ontario, windbreak use was highest in the southwest, along Lake Erie. This distribution corresponds to areas where agriculture is most intensive and where soils are prone to wind erosion (Coote et al., 1981). In Alberta, windbreak use is highest in the centre of the province and lowest in the south, although relative wind erosion risk is high in southern Alberta (Coote et al., 1981).

There are relatively few windbreaks in southeastern and central-eastern Alberta, even though the risk of

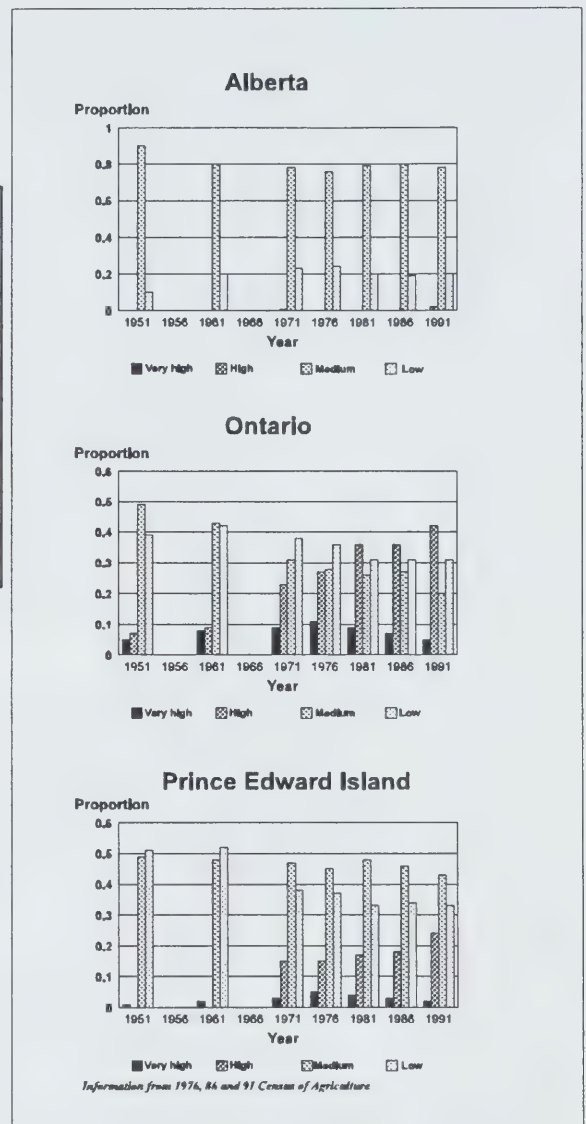


Figure 5. Proportions of cropland in very high, high, medium and low soil degradation risk crops in Alberta, Ontario and P.E.I. from 1951 - 1991.

wind erosion is medium to high (Figure 7). There is considerable overlap between the distribution of summerfallow (a practice that potentially increases the susceptibility of soil to wind erosion) and areas at risk of wind erosion.

In Ontario, areas along Lake Erie use windbreaks, but sandy soils along the north shore of Lake Ontario are also susceptible, particularly where they are used for corn or potatoes (Coote et al., 1981). Wind erosion risk is also high in parts of south-central and southwestern Ontario.

Windbreak density in P.E.I. is intermediate to that of Alberta and Ontario. Wind erosion risk is high in the central and eastern portions of the province due to the combination of sandy soils, high winds and a large proportion of cultivated land (Coote et al., 1981). The proportion of cropland in conservation tillage in P.E.I. is low, thereby giving only marginal erosion control by these means.

The fact that the farmers in an area susceptible to wind erosion do not tend to make great use of windbreaks does not indicate unsustainable land management practices. In fact, Census data show that farmers in southern Alberta and some erosion-prone areas in southern Ontario are more likely to use conservation tillage than windbreaks. The use of windbreaks, then, is only one factor in a package of land management practices, all of which need to be considered in order to determine the sustainability of a particular farming system.

3. Economic

Gross margin with and without government support. Gross margins were positive in all CCSs in Alberta and Ontario in 1991 (1991 census), indicating a positive situation in terms of economic viability. Gross margins were low in northern Alberta and in parts of central Ontario, however, and some of these regions had negative gross

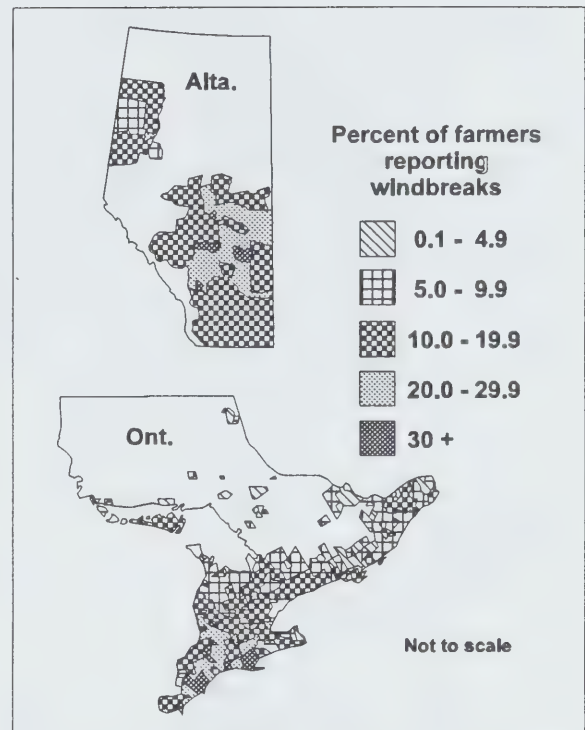


Figure 6. Percent of farmers reporting the use of windbreaks. Census of Agriculture, 1991.

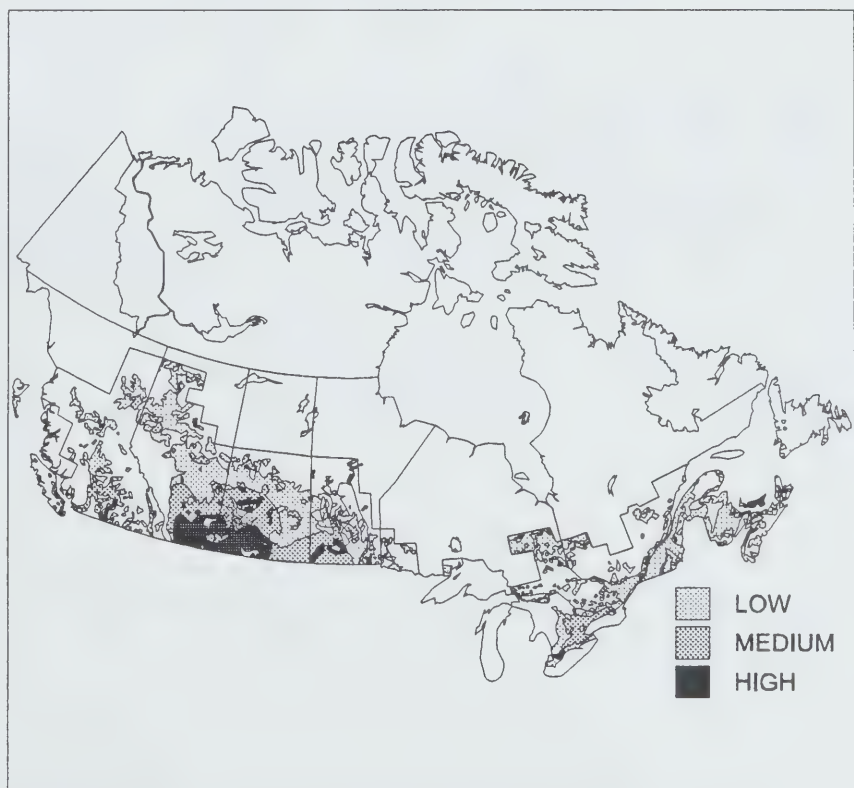


Figure 7. Relative wind erosion risk in Canada. From Coote (1983).

margins in 1986 (1986 census). These low and negative gross margins may indicate that long term viability in these areas may be uncertain.

Gross margin/acre was determined in 1991 for three crops in Strathmore, Alberta with and without government support payments (Figure 8). Gross margin/acre is positive for all three crops when government support payments are included. However, spring wheat has a negative gross margin without government support payments. Both canola and feed barley have positive gross margins without government support payments, indicating a potential for greater economic sustainability than spring wheat in this specific example.

A similar analysis for Ridgetown, Ontario, indicates that gross margin/acre is larger with government support payments than without such payments for corn-soybeans, corn, soybeans and cereals, and corn-soybeans-cereals-others rotations (not shown). Gross margin/acre is still positive without government support payments, suggesting greater economic sustainability than for spring wheat in Strathmore.

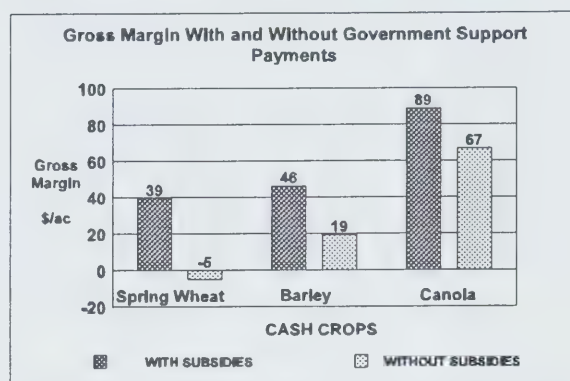


Figure 8. Gross margin with and without government support payments for three crops in Strathmore, Alberta.

Probability of obtaining breakeven yield. The probability of obtaining a breakeven yield was estimated (Figure 9) using effective precipitation and current (1992) price information (De Jong et al., 1993). The probability was highest in central and northern Alberta and Saskatchewan and throughout Manitoba, and lowest in southeastern Alberta and southern Saskatchewan. These results are in agreement with the Physical Land Flexibility index. The probability of obtaining breakeven yields appears to be a useful and easily understood factor which could be used in conjunction with other factors in the determination of economic sustainability.

Debt load. The ratio of interest paid on operating debt to gross margin was determined for each CCS in Alberta, Ontario and P.E.I. as an illustration of debt load. In Alberta, debt load was highest in the northern and eastern portions of the province, where often more than one dollar is paid in interest for every dollar made (Figure 10). This debt load contributes to unsustainability, and if this trend continues, farm operations in these areas could not survive without financial assistance. In southern Ontario, debt load is also high in the northern areas, but generally lower than that in Alberta (Figure 10). Debt load is low in P.E.I., averaging \$0.283 for every dollar of gross margin.

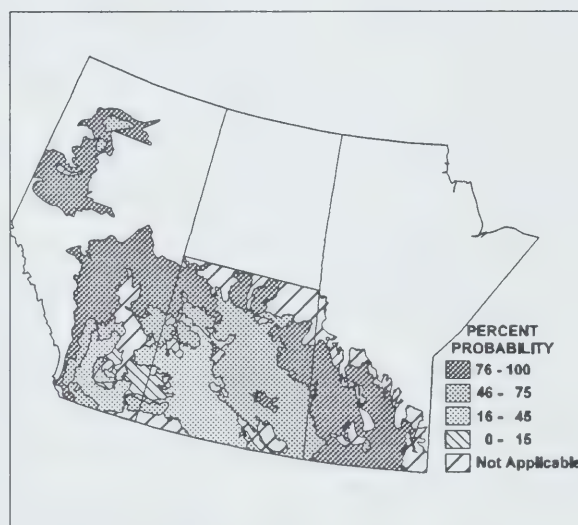


Figure 9. Probability of obtaining breakeven yield based on effective precipitation and current prices. From De Jong et al., 1993.

4. Social

Conservation tillage. An increase in the area of conservation tillage is a positive indicator of sustainable land management, because conservation tillage embodies several of the goals of sustainable agriculture (FPACES, 1990): it promotes the conservation of soil, thereby promoting long term productivity; it improves water quality by decreasing runoff; it is compatible with the conservation of some wildlife, and it reduces dependence on non-renewable fossil fuels.

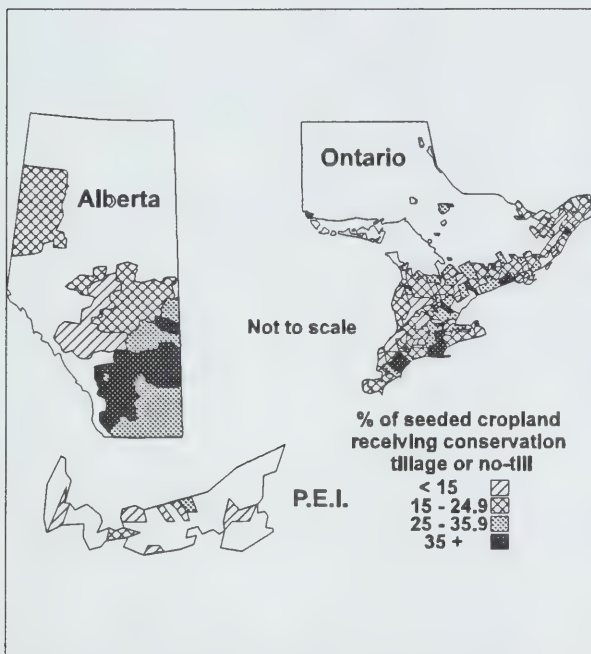


Figure 11. Percent of seeded farmland receiving conservation tillage or no-till. Areas are shown only where total farm area is greater than 9.9% of the CCS. Largest value = 65%. Adapted from Dumanski et al, 1994.

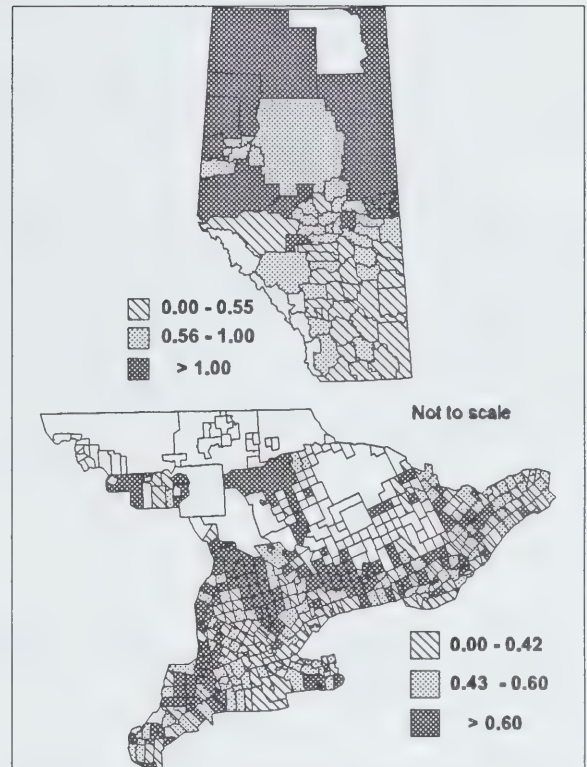


Figure 10. Debt load (interest/gross margin) for CCSs in Alberta and southern Ontario.

Conservation tillage is not used extensively in Alberta, Ontario and P.E.I. (Figure 11). The proportion of area under conservation tillage, as reported in the 1991 census, is generally low, averaging 24%, 18% and 8% of prepared seedbed in the three provinces respectively. The use of no-tillage is also very low, averaging 2.7%, 4.6% and 0.9% of seeded land respectively. However, as discussed in the section about windbreaks, conservation tillage is often concentrated on lands that are susceptible to erosion in Alberta and Ontario.

Conclusions

This report illustrates how various indicators can be used for assessing sustainable land management. Several examples of useful indicators are assessed for physical, agronomic, economic and social indicators. Indicators can be used to identify geographic areas or management practices which require improvement.

Under the Framework for Evaluating Sustainable Land Management, indicators and thresholds are intended to assess and monitor progress towards sustainable land management. An important step in this process will be to integrate the indicators from various aspects of land management at the farming system level. In doing so, a variety of indicators from all of the four categories of SLM must be considered simultaneously. This report makes an attempt to develop such procedures. For example, one method is to compare risk of degradation with areas receiving control measures, as shown in the sections dealing with wind erosion risk, windbreak density and conservation tillage. This method provides some assessment of the system, although in this report the level of analysis is still very general.

The use of thresholds can provide another means for assessing a system's performance. For example, a threshold for sustainable gross margin is 0.0 \$/ha; below this value, the farming system is losing money, above it the system is making money. If, when observed over time, the trend is consistently above or below the threshold value, a determination of sustainability or unsustainability can be made.

Unfortunately, thresholds are not yet available for many indicators, and research is needed to determine threshold values. Also, because a time factor is intrinsic within the meaning of the term 'indicator', historic data will need to be collected in order to determine the trend of indicators within present systems, and plans will need to be made to monitor ongoing trends.

Appendix I

Alternative Approaches to the Development of Indicators

The System Approach

The index method can be used to assess an entire system. In this approach, a numerical value is assigned to an indicator, depending on its position. The sum of these values for chosen indicators is a rough sustainability index. An example of this method can be found in House (1990), who uses this method to assess water quality in England. This method has several limitations; for example, all indicators are assumed equal, and the thresholds assigned for determining index values for each indicator are not unequivocal. Despite these limitations, this method is still useful, since it provides an unbiased evaluation of a large number of indicators. The effect of these limitations can be reduced by carefully considering which indicators should be chosen in the analysis. The following indicators might be useful in this type of index analysis:

1. Physical: Physical land flexibility
2. Agronomic: Cropping intensity
 Yield variability
 Summerfallow - proportion of SF area in chemical only and combination
 Nutrient management- the ratio of nutrients extracted by crops to nutrients added to the soil through fertilizers and manures
 Crop influence - ratio of soil building to soil depleting crops
3. Economic: Probability of obtaining breakeven yield
 Chemical and tillage weed control
 Gross margin
 Debt load
4. Social: Windbreak density - with respect to wind erosion risk
 Adoption of conservation tillage.

Acquiring all the relevant information to determine a value for this index is beyond the scope of this report.

Stability Analysis

Stability analysis, or resilience, is a system indicator which could potentially be used to assess sustainability. The capacity of a system to resist damage from external forces is an important component of sustainability (Huffman, 1990), and failure to recover from stressful events leads to system collapse, which is absolute unsustainability (Fresco and Kroonenberg, 1992).

Stability or resilience is defined as the ability to recover from a disturbance (Hurd and Wolf, 1974). When a system is disturbed from equilibrium or normal state, say by pesticide application or tillage, it will move away from equilibrium. The system will then either return to original equilibrium, move to a new equilibrium, or cease to exist in its initial state, depending on the size of the disturbance. For small scale disturbances such as tillage, the system should return to initial equilibrium (Neave, 1992). The time taken to return to equilibrium (return time), and the amount the system was shifted away from equilibrium (deflection), are indicators of the system's stability. Return time and deflection can be determined for a number of variables within a system, allowing different systems to be compared. The smaller the deflection and the faster the return time the more

stable a system is (Hurd and Wolf, 1974). Systems which can recover from disturbance are more sustainable over time than those that cannot. This concept of sustainability only holds true if the system does not enter a series of temporary equilibriums at constantly lower levels of quality and productivity.

Appendix II

Indicators of Soil and Water Quality

Soil quality

Theoretical indicators of soil quality have been developed by Parr et al. (1992), whose Soil Quality Index states that soil quality is a function of soil properties, potential productivity, environmental factors, food quality and health, erodibility, biological diversity and management inputs. Soil quality has been defined as the capacity of a soil to produce healthy crops, resist erosion, and reduce the impact of environmental stresses on plants (Papendick and Parr, 1992). Soil quality describes how effectively a soil will accept, hold and release nutrients and water, promote and sustain root growth, maintain suitable biotic habitat, respond to management, and resist degradation (Larson and Pierce, 1991). Another consideration is the community of soil organisms. A soil with a dynamic community of organisms capable of decomposition and pest control is of higher quality than a soil with a depauperate fauna, capable of only some functions. In addition, soil organisms are important in nutrient cycling and in the maintenance of soil conditions such as structure and porosity (Hendrix et al., 1990). A decline in organism numbers is indicative of changes within the system and of changes in production potential. Thus, soil organisms are useful indicators of the sustainability of resource use because they are directly affected by subtle changes in soil quality.

Greer et al. (1983) are developing a framework for assessing and predicting soil quality and soil quality change. Arshad and Coen (1992), Larson and Pierce (1991) and the environmental assessment of GRIP and NISA (Gray et al., 1992) have produced, or are using, minimum data sets of physical and chemical soil characteristics to assess soil quality. These variables are most affected by degradation processes. Descriptions of numerous other physical and chemical soil properties are found in FAO (1983a), Klute (1986), Page (1982) and Sheldrick (1984).

Many organisms are bioindicators in agriculture, (Neave, 1992). Previous studies have identified the following microorganisms and processes as being the most sensitive to change caused by chemical application: populations of nitrifiers, Rhizobium, actinomycetes, organic material degradation, and nitrification rates (Visser and Parkinson, 1992). Earthworms are commonly recommended indicators of soil quality as they have influence on soil fertility and structure, there are a small number of species, and there is a large volume of background information (Lee, 1992).

Earthworms are also an excellent example of keystone species and environmental engineers i.e., organisms which influence many other organisms. Earthworm digestion favours certain microorganisms over others (Shaw and Pawluk, 1986), their litter fragmentation activities promote organism growth (Ghilarov, 1963), and they influence soil structure creating habitat for mobile arthropods. Earthworms are sensitive to change in their environment (Edwards, 1975), but only over long periods of time (Neave, 1992). Other more sensitive species such as nematodes should be considered with earthworms to assess shorter term change. Earthworm mass and species richness, and number of nematodes are simple and suitable bio-indicators (Neave, 1992). Other organisms that are responsive to disturbances include sowbugs (Isopoda), slugs, and cryptozoic (soil surface) invertebrates (Neave, 1992).

Water quality

Water quality is of concern in agriculture largely because of the potential off-site effects of intensive production. Nutrients, pesticides and sediments from agricultural land often end up in surface or groundwater (Environment Canada, 1991). Agriculture has been identified as the largest non-point source of surface water pollution in the U.S. (National Research Council, 1989). The Ontario Farm Water Benchmarks Program has

recently found that 13% of farm wells exceeded levels of maximum acceptable nitrate (10 mg/L), 31% exceeded the maximum acceptable level for coliform bacteria, and 4% of wells had pesticide residues (Infosource, 1992). Sustainability requires the minimization, and eventual elimination, of harmful off-site impacts.

Useful indicators of water quality in agriculture should identify off-site impacts, as well as problems with water used for livestock and irrigation. Extensive lists of indicators and guidelines with regard to water quality are available in Environment Canada (1987) and from the Ontario Ministry of the Environment (1977). House (1990) has created a useful water quality index which combines indicators and ranks water on a 10-100 scale. Only indicators suitable for assessing off-site effects are discussed in this report.

References

- (AES) Atmospheric Environment Service, 1985. Monthly Record, Meteorological Observations in Canada. Environment Canada, Downsview, Ontario.
- Alberta Discussion Paper, 1992. Resource accounting-operationalizing sustainable development for Alberta. A discussion paper of the resource accounting working group. Government of Alberta and The University of Alberta.
- Alexandratos, N., 1988. Editor. World agriculture: toward 2000; an FAO study. Belhaven Press, London, England.
- Antrop, M., 1990. Carrying capacity: a view from human ecology. In: M. Husain, ed. Environmental pollution, sustainable development and environmental impact assessment. Rima Publishing, New Delhi.
- Arshad, M. A., and Coen, G. M., 1992. Characterization of soil quality: physical and chemical criteria. *American Journal of Alternative Agriculture* 7: 25-31.
- Asselstine, A., and Girard, L., 1992. Canadian fertilizer consumption, shipments and trade 1990/91. Farm Input Markets Unit, Farm Development Policy Directorate, Agriculture Canada.
- Baier, W., 1990. Characterization of the environment for sustainable agriculture in semi-arid tropics. Pp. 90-128. In: R. P. Singh, ed. Sustainable Agriculture, Vol. 1: Issues, Perspectives and Prospects in Semi Arid Tropics. Proceedings of the International Symposium on Natural Resource Management for a Sustainable Agriculture, Central Research Institute for Dryland Agriculture, Hyderabad 500 659, India.
- Baier, W., Dyer, J. A., and Sharp, W. R., 1979. The versatile soil moisture budget. Technical Bulletin 87, Agrometeorology Section, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Bootsma, A., Blackburn, W. J., Stewart, R. B., and Muma, R. W., 1984. Possible effects of climatic change on estimated crop yields in Canada. Technical Bulletin 1984 - 9E Land Resource Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Bott, T. L., 1973. Bacteria and the assessment of water quality. In: J. Cairns Jr. and K. L. Dickson eds. Biological Methods for the assessment of water quality: a symposium presented at the seventy-fifth annual meeting, American Society for Testing and Materials. ASTM Special Technical Paper 528, American Society for Testing and Materials, Philadelphia.
- Bryson, R. A., 1989. Environmental opportunities and limits for development. *Environmental Conservation* 16: 299-305.
- Coote, D. R., 1983. Stresses on land under intensive agricultural use. In: W. Simpson-Lewis, ed. Stress on Land, Lands Directorate, Environment Canada, Ottawa, Ontario.
- Coote, D. R., Dumanski, J., and Ramsey, J. F., 1981. An assessment of the degradation of agricultural lands in Canada. LRRI contribution No. 118, Research Branch, Agriculture Canada, Ottawa, Ontario.

- Costanza, R., Daly, H. E., and Bartholomew, J. A., 1991. Goals, agenda, and policy recommendations for ecological economics. *In*: R. Costanza, ed. *Ecological Economics: the science and management of sustainability*. Columbia University Press, New York.
- Coupland, R. T., 1982. Nutrient balance in the croplands of the world. Environment Canada, Ottawa, Ontario.
- Crews, T. E., Mohler, C. L., and Power, A. G., 1991. Energetics and ecosystem integrity: the defining principles of sustainable agriculture. *American Journal of Alternative Agriculture* 6: 146-149.
- De Jong, R., Dumanski, J., and Bootsma, A., 1993. Moisture risk for the prairies. Lethbridge conference on sustainable land management. Centre for Land and Biological Resource Research, Research Branch, Agriculture Canada, Ottawa, Ontario.
- De Jong, R., Bootsma, A., Dumanski, J., and Samuel, K., 1992. Characterizing the soil water regime of the Canadian prairies. Technical Bulletin 1992-2E. Centre for Land and Biological Resources Research, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Dumanski, J., Cann, M., and Wolynetz, M. S., 1992. Identification of crop production risks in Manitoba based on agroecological resources. Research Branch, Agriculture Canada, Ottawa, Ontario.
- Dumanski, J., Eswaran, H., and Latham, M., 1991. A proposal for an international framework for evaluating sustainable land management. *In*: Evaluation for sustainable land management in the developing world. Vol. 2, Technical papers. Bangkok, Thailand: International Board for Soil Research and Management, 1991. IBSRAM Proceedings no. 12 (2).
- Dumanski, J., Gregorich, L. J., Kirkwood, V., and Cann, M. A., 1994. The Status of Land Management Practices on Agricultural Land in Canada. Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Ottawa, Ontario.
- Dumanski, J. and Smyth, A. J., 1994. The Issues and Challenges of Sustainable Land Management. *In*: R. C. Wood and J. Dumanski, eds. *Proceedings of the International Workshop on Sustainable Land Management for the 21st Century*. Vol. 2: Plenary Papers. The Organizing Committee. International Workshop on Sustainable Land Management. Agricultural Institute of Canada, Ottawa, Ontario.
- Dumanski, J., Zeng, Z. Y., and Kirkwood, V., 1988. Assessing the physical land flexibility of the prairie region of western Canada. *In*: J. Dumanski and V. Kirkwood, eds. *Crop production risks in the Canadian prairie region in relation to climate and land resources*. Technical Bulletin 1988-5E, Land Resource Research Centre, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Dyer, J. A., and Mack, A. R., 1984. The versatile soil moisture budget -version 3. Technical Bulletin 1984-1E. Research Branch, Agriculture Canada, Ottawa, Ontario.
- Edwards, C. A., 1977. Investigation into the influence of agricultural practice on soil invertebrates. *Annals of Applied Biology* 87: 515-520.
- (EMA) Environmental Management Associates, 1992. Environmental assessment of GRIP and NISA: a national survey of GRIP and NISA participants. Calgary, Alberta.

- Environment Canada, 1987. Canadian water quality guidelines. Task force on water quality guidelines of the Canadian Council of Resource and Environment Ministers, Ottawa, Ontario.
- Environment Canada, 1988. Summary of national planning workshop on state of the environment reporting, Ottawa, Ontario.
- Environment Canada, 1991a. A report on Canada's progress towards a national set of environmental indicators. Indicators task force, State of the Environment Reporting. State of the Environment Report 91-1, Ottawa, Ontario.
- Environment Canada, 1991b. The state of Canada's environment. Ministry of Supply and Services, Ottawa, Ontario.
- Environment Canada, 1992. A draft state of environment paper on soil indicators.
- Everts, J. W., 1990. Sensitive indicators of side-effects of pesticides on the epigeal fauna of arable land. Landbouwniversiteit te Wageningen.
- FAO, 1983a. Guidelines: land evaluation for rainfed agriculture. Soils Bulletin 52, FAO, Rome.
- FAO, 1983b. Economic and social development paper 30: agriculture from the perspective of population growth. FAO, Rome.
- FAO, 1984. Land, food and people. FAO, Rome.
- Flaten, D. N., and Hedlin, R. A., 1988. Impact of technology on crop productivity in western Canada. Proceedings of the 34th Annual Meeting of the Canadian Society of Soil Science, Calgary, Alberta.
- (FPWGPR) Federal-Provincial Working Group on Program Review, (Canada) 1991. Growing together. Report to Ministers of Agriculture. Agriculture Canada, Ottawa, Ontario.
- (FPACES) Federal-Provincial Agriculture Committee on Environmental Sustainability, 1990. Growing together. Report to Ministers of Agriculture.
- Fresco, L. O., and Kroonenberg, S. B., 1992. Time and spatial scales in ecological sustainability. In: Land Use Policy, Butterworth-Heinemann Ltd., Oxford.
- Ghilarov, M.S., 1963. On the interrelations between soil dwelling invertebrates and soil microorganisms. Pp. 255-265 In: J. Doeksen, and J. Van der Drift ed. Soil Organisms: proceedings of the Colloquium on Soil Fauna, Soil Microflora and their Relationships. Oosterbeed, the Netherlands, September 10-16, 1962. North Holland Publishing Company, Amsterdam.
- Goddard, T., 1992. Farm Conservation Planning: draft version. Alberta Agriculture, Conservation and Development Branch.

- Gray, B. T., Macdonald, G., Young, D. A., Courtney, R. F., Kraft, D., and Furtan, H., 1992. Environmental assessment of GRIP and NISA: interim report 2. Environmental Management Associates, Calgary, Alberta.
- Greer, K. J., Acton, D., and Schoenau, J. J., 1993. Developing a national framework to assess soil quality. National Soil Quality Evaluation Project, Saskatoon, Saskatchewan.
- Gregorich, E., Carter, M., Angers, D., Ellert, B., and Monreal, C., 1994. Towards a minimum data set for soil organic matter quality. *Can. J. Soil Sci.* **74**: (in press).
- Hamblin, A., 1992. Environmental indicators for sustainable agriculture. Report on a national workshop, November 28-29, 1991. Bureau of Rural Resources, Land and Water Resource Research and Development Corporation, Grains Research and Development Corporation, Canberra.
- Hendrix, P. F., Crossley, D. A. Jr., Blair, J. M., and Coleman, D. C., 1990. Soil biota as components of sustainable agroecosystems. Pp. 637-654. *In*: C. A. Edwards, R. Lal, P. Modden, R. H. Miller, and G. House, eds. Sustainable Agricultural Systems. Soil and Water Conservation Society, Ankeny, Iowa.
- House, M. A., 1990. Water quality indices as indicators of ecosystem change. *Environmental Monitoring and Assessment* **15**: 255-263.
- Huffman, E., 1990. Workgroup issue paper: indicators and assessment of agricultural sustainability. *Environmental Monitoring and Assessment* **15**: 303-305.
- Hurd, L. D., and Wolf, L. L., 1974. Stability in relation to nutrient enrichment in arthropod consumers of old field successional ecosystems. *Ecological Monographs* **44**: 465-482.
- (IBSRAM) International Board for Soil Research and Management, 1991. Evaluation for sustainable land management in the developing world. Volume 1. Towards the development of an international framework. Bangkok, Thailand: International Board for Soil Research and Management, 1991. IBSRAM Proceedings no. 12.
- InfoSource, 1992. Ontario farm water benchmarks. Soil and Water Conservation Information Bureau, Guelph, Ontario.
- Keeney, D. R., 1989. Toward a sustainable agriculture: need for clarification of concepts and terminology. *American Journal of Alternative Agriculture* **4**: 101-105.
- Klute, A., ed, 1986. Methods of soil analysis. Part 1. 2nd ed. Agronomy Monograph 9. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.
- Larson, W. E., and Pierce, F. J., 1991. Conservation and enhancement of soil quality. *In*: Evaluation for sustainable land management in the developing world. Volume 2: Technical papers. Bangkok, Thailand: International Board for Soil Research and Management, 1991. IBSRAM Proceedings no. 12 (2).

- Lee, K., 1992. Where does biodiversity fit? In: A. Hamblin, ed. 1992. Environmental indicators for sustainable agriculture. Report of a national workshop. Bureau of rural resources, Land and Water Resource Research and Development Corporation, Grains Research and Development Corporation, Canberra.
- MacRae, R. J., Hill, S. B., Henning, J., and Bentley, A. J., 1990. Policies, programs, and regulations to support the transition to sustainable agriculture in Canada. *American Journal of Alternative Agriculture* 5: 76-89.
- Munn, R. E., 1990. Towards sustainable development: an environmental perspective. In *Economy and ecology: towards sustainable development*. Kluwer Academic Publishers, The Netherlands.
- National Research Council, 1989. Alternative agriculture: committee on the role of alternative farming methods in modern production agriculture. National Academy Press, Washington, D.C.
- Neave, P. R., 1992. The response of soil microflora and fauna to plowing of zerotill and old field soils. Unpublished M. Sc. Thesis, University of Guelph, Guelph, Ontario.
- OECD, 1993 draft. Indicators for the integration of environmental concerns into agricultural policies. Group on the State of the Environment, Environment Directorate, Agriculture Canada, Research Branch, Saskatoon, Saskatchewan.
- Ontario Ministry of the Environment, 1977. Water quality data for Ontario lakes and streams. Volume XII. Ontario Ministry of the Environment, Water Resources Branch, Toronto, Ontario.
- Page, A. L. ed., 1982. Methods of soil analysis. Part 2. 2nd ed. Agronomy Monograph 9. American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin.
- Papendick, R. I., and Parr, J. F., 1992. Soil quality- the key to a sustainable agriculture. *American Journal of Alternative Agriculture* 7: 2-3.
- Parr, J. F., Papendick, R. I., Hornick, S. B., and Meyer, R. E., 1992. Soil quality: attributes and relationship to alternative and sustainable agriculture. *American Journal of Alternative Agriculture* 7: 5-11.
- Potvin, J. R., 1991. Indicators of ecologically sustainable development: synthesized workshop proceedings. Canadian Environment Advisory Council, Minister of Supply and Services, Ottawa, Ontario.
- Rapport, D., 1990. Workshop issue paper: criteria for ecological indicators. *Environmental Monitoring and Assessment* 15: 273-275.
- Repetto, R., 1992. Accounting for environmental assets. *Scientific American*, June, 1992. Pp. 94-100.
- Salisbury, F. B., Ross, C., 1969. Plant physiology. Wadsworth Publishing Company, Inc, Belmont, CA.
- Science Council of Canada, 1992. Sustainable agriculture: the research challenge. Science Council of Canada Report 43, Ottawa, Ontario.

- Shaw, C., and Pawluk, S., 1986. Faecal microbiology of Octolasion tyrateum, Aporrectodea turgida and Lumbricus terrestris and its relation to the carbon budgets of three artificial soils. *Pedobiologia* 29: 377-389.
- Sharpley, A. N., and Williams, J. R., 1990. EPIC-Erosion/Productivity Impact Calculator:1. Model documentation. U.S. Department of Agriculture Technical Bulletin No. 1768, Washington, D.C.
- Sheldrick, B. H. ed. 1984. Analytical methods manual 1984. LRRI contribution No. 84-30, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Sly, W. K., 1982. Agroclimatic maps for Canada - derived data: soil water and thermal limitations for spring wheat and barley in selected regions. *Agrometeorology Technical Bulletin* No. 88, Land Resource Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario.
- Sly, W. K., and Colidago, M. C., 1974. Agroclimatic maps for Canada - derived data: Moisture and critical temperatures near freezing. *Agrometeorological Research and Services, Chemistry and Biology Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario.*
- Smyth, A. J. and Dumanski, J., 1993. FESLM: An international framework for evaluating sustainable land management. A Discussion Paper. World Soil Resources Report 73. Land and Water Development Division, FAO, Rome.
- Southwood, T. R. E., 1966. Ecological methods, with particular reference to the study of insects. Methuen, London.
- Statistics Canada, 1992. Environmental information system, data dictionary. Environmental and Natural Resources Section, National Accounts and Environment Division, System of National Accounts Branch, Ottawa, Ontario.
- Trietz, W., 1991. Dimensions and importance of sustainability in a global context. *In* Evaluation for sustainable land management in the developing world. Volume 2: Technical papers. Bangkok, Thailand: International Board for Soil Research and Management, 1991. IBSRAM Proceedings no. 12 (2).
- Victor, P. A., Kay, J. J., and Ruitenbeek, H. J., 1991. Economic, ecological, and decision theories. Canadian Environmental Advisory Council, Minister of Supply and Services Canada, Ottawa.
- Visser, S., and Parkinson, D., 1992. Soil biological criteria as indicators of soil quality: soil microorganisms. *American Journal of Alternative Agriculture* 7: 33-37.
- Walker, J., and Jones, B., 1992. What is meant by indicators and the decisions behind those chosen for Environmental Monitoring and Assessment Program (EMAP) of the U.S.-EPA. *In* Hamblin, A. (ed.), 1992. Environmental indicators for sustainable agriculture. Report on a national workshop, November 28-29, 1991. Bureau of Rural Resources, Land and Water Resource Research and Development Corporation, Grains Research and Development Corporation, Canberra.

- (WCED) World Commission on Environment and Development. Advisory Panel on Food Security, Agriculture, Forestry, and Environment, 1987. Food 2000: global policies for sustainable agriculture: a report of the Advisory Panel on Food Security, Agriculture, Forestry, and Environment to the World Commission on Environment and Development. Zed Books, London, New Jersey.
- (WMO) World Meteorological Organization, 1983. Guide to meteorological instruments and methods of observation. WMO No. 8. World Meteorological Organization, Geneva, Switzerland.

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